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Ground Test and Evaluation Methodologies and Techniques for the Development of Endoatmospheric Interceptors

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GROUND TEST AND EVALUATION METHODOLOGIES AND TECHNIQUES FOR THE DEVELOPMENT OF ENDOATMOSPHERIC INTERCEPTORS*

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Abstract

The cornerstone of the Strategic Defense Initiative (SDI) is the development of ground-based interceptors for late midcourse and terminal tactical and strategic missile defense. Kinetic energy-type interceptors for ballistic missile defense have evolved from command guided concepts with nuclear warheads such as Nike Zeus in the early 1960s and SPRINT and Spartan in the late 1960s and early 70s. The family of Theater Missile Defense (TMD) and National Missile Defense (NMD) interceptors currently under development make up the national initiative of providing Global Protection Against Limited Strike (GPALS).

Selection of a ground-based interceptor airframe design is an iterative process that compromise among aerodynamic, aerothermal, weather/erosion, and lethality requirements. The design validation process requires high-quality ground test data to validate engineering designs, simulation and control models, material and component performance, and lethality assessments.

This paper will focus on capabilities and test techniques of the AEDC facilities which are applicable to the development of ground-based interceptors. Also, a brief overview of the AEDC test support service and capabilities and supersonic/hypersonic-related technology programs will be provided.

Introduction

The long-range SDI goals[1] for development of interceptor missile technologies indicate a critical need for accurate ground test simulation of hypersonic flight regimes through the transatmospheric flight corridor. Critical technologies and components under development for interceptor systems require rigorous testing in ground simulation facilities to verify performance and survivability over a wide range of endoatmospheric test conditions. A broad range of mission requirements and scenarios for interceptor systems places extreme demands on aerostructures, control/divert components, seekers and windows, and thermal protection components, such as nosetips, shrouds, and heatshields. With design intercept velocities up to 5 km/sec and target velocities up to 6 km/sec, performance and survivability verification of each component of the flight system is critical if operational flight vehicles are to achieve the hit-to-kill intercept margins typically required.

Ground test facilities used to evaluate aerodynamic and aerothermal performance of proposed flight hardware typically include supersonic and hypersonic wind tunnels, ballistic ranges, weather/erosion test facilities, and high-enthalpy facilities such as arc heaters and combustion-heated test units. The Arnold Engineering Development Center (AEDC) has a long history of providing ground test data and support to such interceptor programs as SPRINT, Patriot, Extended Range Intercept Technology (ERINT), Arrow, High Endoatmospheric Defense Interceptor (HEDI), Theater High Altitude Area Defense (THAAD), and Endoatmospheric Lightweight Projectile (ENDO LEAP). The AEDC facilities have been designed to provide high-quality data necessary to support programs from design verification through post-production improvements. Typically, AEDC involvement starts early in the demonstration/validation phase and continues through the life of a program. Early in a program, tests will be performed with vehicle engineering models, and progress to component and flight hardware testing.

AEDC is comprised of three major facility complexes: the Engine Test Facility (ETF), the Propulsion Wind Tunnel Facility (PWT), and the von Karman Gas Dynamics Facility (VKF). An overview description of the facilities and capabilities for each of the three

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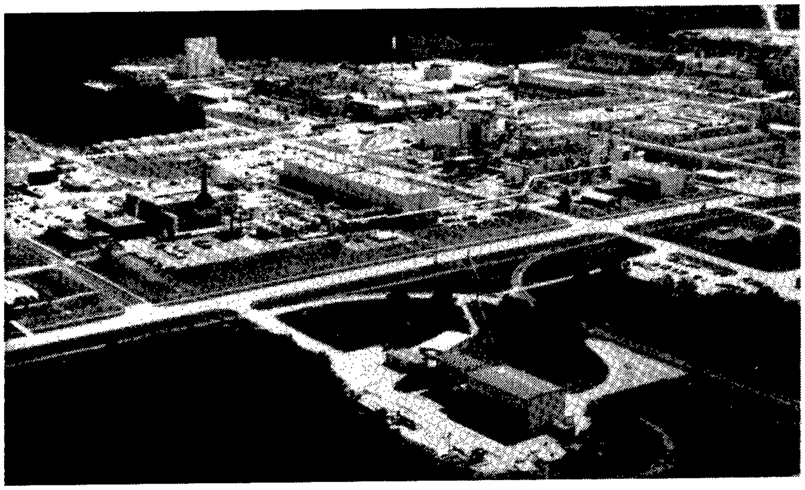


Fig. 1. AEDC von Karman Gas Dynamics Facility (VKF).

complexes is contained in Ref. 2. The principal ground test facilities for the development of supersonic/hypersonic interceptors are located within the VKF complex (aerial view in Fig. 1). The VKF aerospace facilities and equipment permit testing of relatively large-scale models of defensive systems such as interceptors and missiles, high-speed aircraft, and launch vehicles in a Mach number range extending from 1.5 to 20. The test units, or facilities, include conventional continuous-flow wind tunnels, an intermittent blowdown tunnel, a shock tunnel, continuous-flow arc-heated facilities, and ballistic ranges. However, AEDC is much more than a collection of test facilities; it is a national Aerospace Ground Test and Evaluation (T&E) complex which can provide a full range of T&E services tailored to the needs of our customers. Examples of services available include: design and execution of T&E programs, model design and fabrication, selection and installation of state-of-the-art instrumentation, data reduction, data certification, engineering analyses, and reporting. AEDC also performs research associated with ground testing to develop new advanced test facilities, test techniques, and measurement systems.

Supersonic/Hypersonic Facilities and Test Techniques

The applications to which AEDC ground test facilities are most frequently applied in development of ground-based interceptors can be grouped into four general categories: supersonic/hypersonic aerodynamics, aerothermal/structures, weather/erosion, and impact/lethality.

Supersonic/Hypersonic Aerodynamics

The AEDC supersonic/hypersonic aerodynamic facilities consist of continuous-flow Wind Tunnels A,B, and C, Aerodynamic and Propulsion Test Unit (APTU), and Free Piston Shock Tunnel (FPST). Tunnel A is a 40- by 40-in. exit, variable density, supersonic wind tunnel with a Mach number range of 1.5 to 5.5. Tunnels B and C are variable density hypersonic wind tunnels with interchangeable, axisymmetric contoured nozzles. Tunnel B has 50-in. exit diam Mach 6 and Mach 8 nozzles; Tunnel C has a 50-in. exit diam Mach 10 nozzle and 24.5-in. exit diam Mach 4 and 8 nozzles. All three tunnels are continouus-flow devices and are equipped with a model injection system that allows removal of the model from the test section for configuration changes while the tunnel remains in operation. APTU is a blowdown-type facility which uses an isobutane-fueled vitiated air heater (VAH) to preheat the test air. Free-stream Mach numbers ranging from 2.2 to 4.4 are achieved by employing interchangeable, axisymmetric free-jet nozzles. The Free Piston Shock Tunnel (FPST),[3] currently under development is a short duration ($\approx$1 msec) aerodynamic research facility. The facility is designed to operate at stagnation pressures up 10,000 atm. The FPST uses a 3.0-in. bore shock tube coupled to an 8-deg semi-angle conical nozzle (18-in. exit diam) and interchangeable throats. Contoured nozzles will be designed and fabricated for this facility in the future, following shakedown and demonstration. The capabilities of the supersonic/hypersonic aerodynamic facilities are summarized in Fig. 2.

The typical aerodynamic test methodologies employed to determine vehicle performance include: static/dynamic stability and control properties, booster and shroud separation characteristics, jet interaction and control effectiveness, inlet performance, aeroheating and surface pressure distribution, and validation of aerodynamic and aerothermal computations. For static stability and control properties, booster and shroud separation characteristics, jet interaction and control effectiveness test methodologies, the measurement of static force and moments are the critical parameters. The force and moment measurement technique[4] uses a multiple-degree-of-freedom static balance. Force and moment data can be obtained either as individual points in the flight envelope (pitch pause) or in a continuous sweep mode.

A variety of measurement techniques have been developed and applied to the aeroheating and surface pressure distribution, and the code validation test methodologies. Intrusive and nonintrusive flowfield measurements are an integral part of these two test methodologies. An overview of the various AEDC

TUNNEL	TYPE	TEST SECTION SIZE, IN.	MACH NO. RANGE
SUPERSONIC A*	CONTINUOUS	40 × 40	1.5 TO 5.5
HYPERSONIC B*	CONTINUOUS	50 DIAM	6 OR 8
HYPERSONIC C*	CONTINUOUS	50 DIAM	8 OR 10
AEROTHERMAL C*	CONTINUOUS	25 DIAM	4, 8
APTU	INTERMITTENT (FREE JET)	32 DIAM TO 38 DIAM	2.2 TO 4.1
FPST**	SHOCK TUNNEL	18 DIAM	6

* MODEL INJECT SYSTEM
** UNDER CALIBRATION

- HIGH-QUALITY, WELL-CALIBRATED FLOW
- HIGH PRODUCTIVITY

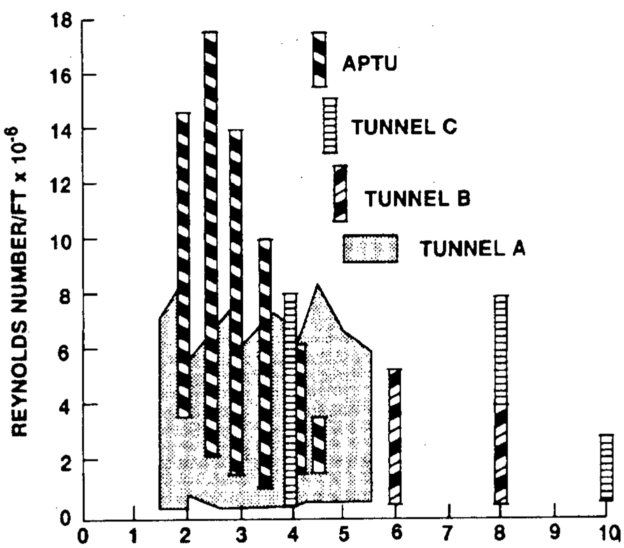


Fig. 2. Supersonic/hypersonic aerodynamic facilities/capabilities.

measurement techniques available for application in the VKF facilities and at other locations will be presented. However, a detailed discussion of the operation and application of each system is beyond the scope of this paper and can be found in the references cited.

Intrusive flow-field and boundary-layer surveys are routinely made with pitot probes, total temperature probes, and Mach/flow angularity probes. Shielded and unshielded total temperature probes are used to measure local temperature. Mach/flow angularity probes measure local stream pitot pressure and determine the local stream static pressure from the cone probe static pressures. Intrusive aerothermal (heat transfer and surface temperature measurements) instrumentation devices and techniques include resistance thermometer gages, Gardon gages, coaxial surface thermocouples, phase-change paint, thermographic phosphor, and infrared scanning camera. The intrusive flow-field diagnostics[5,6] and intrusive aerothermal instrumentation[7] are summarized along with their advantages and disadvantages in Fig. 3.

Advances in applied laser technology have resulted in the recent development of a number of electro-optical systems that permit nonintrusive measurements in the hostile aerothermal environment of supersonic and hypersonic test facilities. A notable feature of these new systems, in addition to being mechanically nonintrusive, is that they often provide measurements that cannot be provided by intrusive devices. Operational systems available[5,8] for use include: Boundary-Layer Transition Detector (BLTD), Laser Particle Monitor (LPM), Laser Doppler Velocimeter (LDV), Laser-Induced Fluorescence (LIF), and Electron Beam Fluorescence (EBF). A summary with applications, advantages, and disadvantages of these systems is provided in Fig. 4.

Aerothermal

The AEDC aerothermal facilities include the arc-heated test units H1, HR, and H2, Wind Tunnels B and C, and APTU. H1 utilizes an advanced performance segmented arc heater producing extremely high-pressure and high-temperature flow. The facility conditions range from temperatures of 3,000 to 13,500°R over a heater pressure range of 20 to 115 atm. The H1 test unit has a mixing air chamber to reduce the temperature through the injection of cold air. HR utilizes a conventional 50-MW Huels-type (N-4) arc heater as the driver. Mass flow rates up to 10 lbm/sec can presently be heated to temperature levels between 6,000 and 12,000°R at arc heater pressure levels to 100 atm. Both H1 and HR test units have a range of contoured nozzles available for matching customer test requirements. The H2 test unit utilizes the same type of N-4 arc heater as HR; however, it uses an enclosed test cell that is evacuated via a diffuser connected to a vacuum plant to provide a high-altitude simulation capability. A three-section, water-cooled conical nozzle with an 8-deg half-angle is presently available. Exit diameters of 9, 24, and 42 in., together with three throat diameters (1.0, 1.5, and 2.0 in.), provide a wide range of free-stream test conditions. All three arc-heated facilities are equipped with multiple model injection and positioning systems. The general description of Tunnels B and C and APTU were given as part of the aerodynamic section.

FLOW-FIELD

TECHNIQUE	PARAMETER	ADVANTAGES	DISADVANTAGES
Pitot Probe	Pitot Pressure	• Direct measurement • Years of experience • Very simple • Relatively insensitive to AOA	• Measurement in boundary layer can be distored (wall effects) • Small probe diameter difficult to fab
Total Temp Probe	Local flow total temperature	• DIrect measurement • Years of experience • Relatively simple	• Measurement in boundary layer can be distored (wall effects) • Small probe diameter difficult to fab
Mach/FLow Angularity Probe	Inferred Mach No. and local flow angle	• Provide basic aerodynamic information • Simple pressure measurement	• Requires extensive calibrations • Fabrication difficult • Large size-distort local flow
Hot Wire (Film) Sensor	Fluctuating stream parameters	• Measure flow fluctuation • Measurements in 500 kHZ	• Sensor survivability • Limited dynamic range

HEAT-TRANSFER INSTRUMENTATION

	ADVANTAGES	DISADVANTAGES
DISCRETE MEASUREMENT		
Thin-Skin	• High quality data • Dense spacing	• Expensive model fabrication • Conduction effects
Coax Gage	• Easy to install, contourable, durable	• Low output • Short test times
Schmidt-Boelter Gage	• High output very durable	• Limited experience
Gardon Gages	• Years of experience • Fast response	• Gage attrition rate • Not contourable
Thin-Film	• Dense spacing small radii • Fast response	• Limited experience • Difficult installation
THERMAL MAPPING		
Phase-Change Paint	• High spatial resolution	• Slow data acquisition
Thermographic Phosphor	• High run rates • Good spatial resolution	• Difficult data reduction and presentation
IR Scanning Camera	• Color mapping, nonintrusive	• Spatial resolution

Fig. 3. Intrusive diagnostics techniques.

TECHNIQUE	PARAMETER	ADVANTAGES	DISADVANTAGES
Boundary-Layer Transition Detector (BLTD)	Boundary-layer state	• Simple setup and operation • Performance comparable with conventional means • Extensive experience	• Viable only in model vertical plane
Laser Particle Monitor (LPM)	Particle flux	• Online data • Simple set-up and operation	• Competes with Schlieren, cameras, etc. for optical access
Laser Doppler Velocimeter (LDV)	Local velocity of particles	• Measures 1, 2, or 3 velocity components • Close to model surface • Experience in aerodynamic and aeropropulsion environment	• Costly, requires support equipment • Large optical access • Gas velocity inferred
Laser-Induced Fluorescence (LIF)	n and T of 0_2, NO, and H_2	• Direct molecular energy state and number density • Instanteous sampling of number density and temperature • Point and planar capability	• Costly primary and support equipment • Setup time significant • Requires UV windows
Electron Beam Fluorescence (EBF)	No. Density Rotational and Vibrational Temperature	• Developed system • Extensive applications	• Difficult to apply problems with beam injection, quenching, and emission

Fig. 4. Nonintrusive diagnostics techniques.

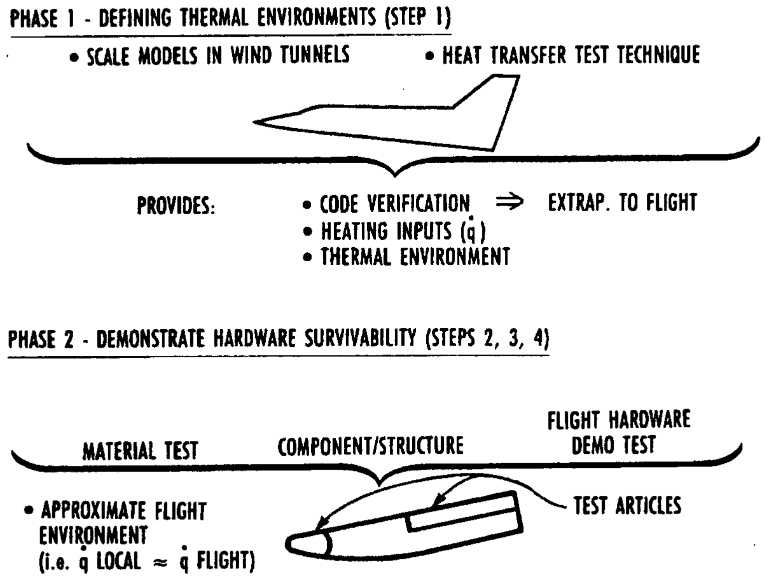


Fig. 5. Methodology for aerothermal materials/components/structures development.

The aerothermal test methodology[9] is a two-phase approach: (1) define the vehicle's thermal flight environment, and (2) demonstrate material, component, and structural survivability and performance (see Fig. 5). The aeroheating test technique developed to approximate the vehicle aerothermal flight environment is provided in aerodynamic facilities such as Tunnels B and C. The results are used for code verification and defining local heat-transfer rates around complex geometries like control surfaces, window apertures, and other protuberances. The test techniques[9] developed for material screening involve placing material samples into specially designed wedges or nosetip holders and inserting the test article into the flow. To match or vary the local surface conditions, the wedge or nosetip pitch angle and model axial location relative to the nozzle exit can be varied. Typically, instrumented models are used to measure the local environment (pressure, surface temperature, and heating rates) before the test article is injected. Test techniques for component and structure performance and survivability make use of the same type of instrumentation. The primary test data for any material test is the posttest model appearance i.e., survivability and ablation response. Figure 6 summarizes the AEDC aerothermal facilities and capabilities.

To supplement the posttest data, AEDC has developed a surface diagnostic system (shown in Fig. 7) for operation in high-temperature flow for the evaluation of ablating materials, components, and structures. This surface planar recession measurement system[10] provides real-time ablation data to complement the posttest recession measurements. As illustrated in Fig. 7, the system uses an argon

TUNNEL	MAX RUN TIME, MIN	MAX NOZZL EXIT, DIAM, IN.	MAX STAGNATION Q_{DOT}*, BTU/FT² S	MAX TOTAL TEMP., °R
H1 ARC	1	3	14,000	13,000
HR ARC	5 TO 10	4	10,500	12,000
H2 ARC	5 TO 10	42	900	12,000
APTU/VAH	10	38	150	1,900
TUNNEL B/C	CONTINUOUS	50 25	30 90	1,900

* BASED ON 1-IN. DIAM NOSETIP

- WIDE RANGE OF AEROTHERMAL ENVIRONMENTS (SUPERSONIC → HYPERSONIC)
- LARGE, HIGH-PRESSURE, HIGH-TEMPERATURE WITH LONG RUN TIME

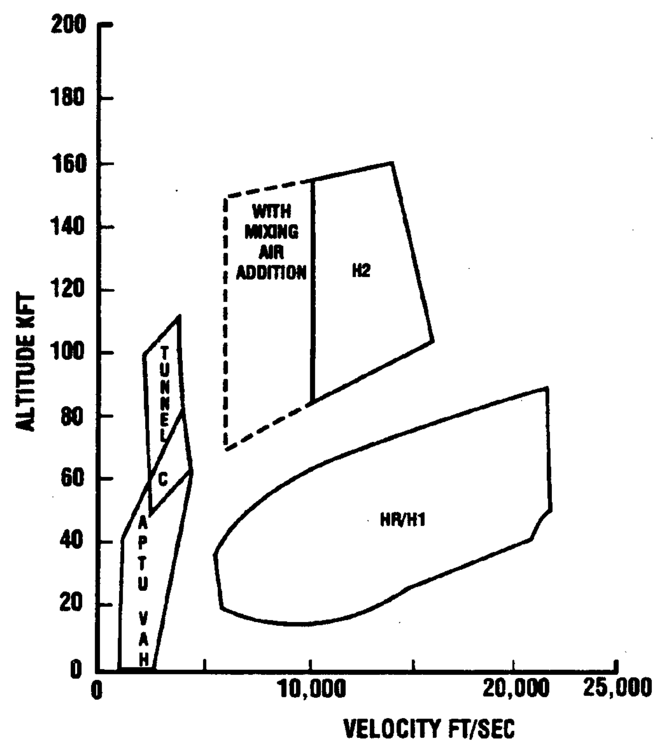


Fig. 6. Aerothermal ground-test facilities.

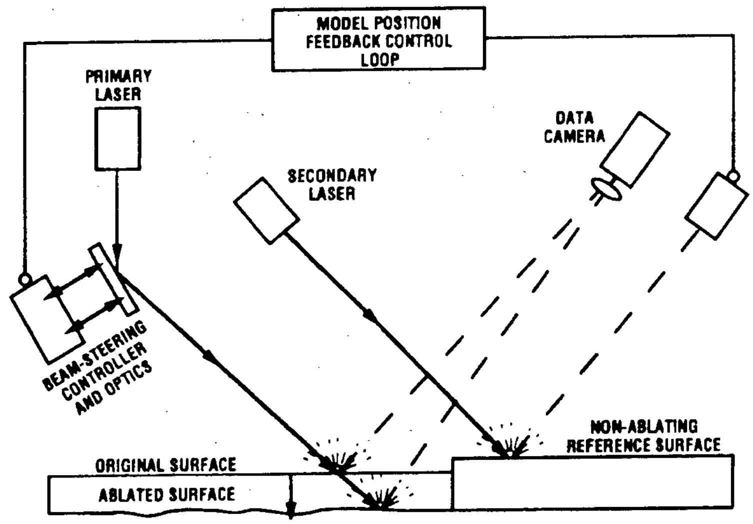


Fig. 7. Surface recession diagnostics.

laser, bandpass filter, and high-speed galvanometer beam steering to write a pre-determined beam grid or spot pattern on the model. As the surface recession proceeds, the recorded laser grid image moves proportionately. The image motion is then related to recession depth via imaging system calibration. The current system will produce ablating time histories for a flat or slightly curved surface. Future plans are to expand the planar system to produce 3-D maps of an ablating surface.

A bench-top instrumentation system has been developed for measuring emissivity as a function of wavelength and temperature. The system has been used to improve surface temperature measurements in high-temperature flows by providing the emissivity constant required to convert surface brightness temperature to surface temperature. Measurements to date have been made on materials such as graphite, boron nitrite, optical silicas, Nitroxyceram, and silicon nitride.

Weather/Erosion

The AEDC facilities with weather/erosion test capabilities include Hypervelocity Range/Track G, Tunnel C, and H1. Range G is a facility for testing subscale models at supersonic to hypersonic speeds (up to 25,000 ft/sec) at environmental conditions. Types of weather/erosion environment that have been developed[11] to date include snowfields consisting of dendritic-crystal snowflakes or cirrus ice, dust fields consisting of spherical particles of various sizes and materials, water droplet clouds consisting of particles less than 100 µm in diameter, and rainfields consisting of approximately 1-mm raindrops.

The models can be tested in a free-flight mode or a track mode where the model can be recovered. The Range G facility is being upgraded by replacing the existing 2.5-in.-bore, two-stage light-gas launcher with a 3.3-in.-bore launcher[3] that has a soft launch capability (reduced launch acceleration loads). Tunnel C simulates a supersonic rain/ice environment. Material samples and components such as radomes (see Fig. 8) can be exposed to a combined aerothermal/weather environment for up to 30 sec. Small ice particles (0.5- to 1.0-mm-diam) are injected into the wind tunnel stilling chamber and drag accelerated through the tunnel nozzle to speeds ranging from 1,500 to 3,000 ft/sec. The precipitation concentration can be varied to a maximum level of 10 gm/m^3. The H1 test unit has the capability to inject graphite particles in the arc section with subsequent acceleration to the test section (to velocities up to 7,000 ft/sec) to provide a combined ablation/erosion test capability.

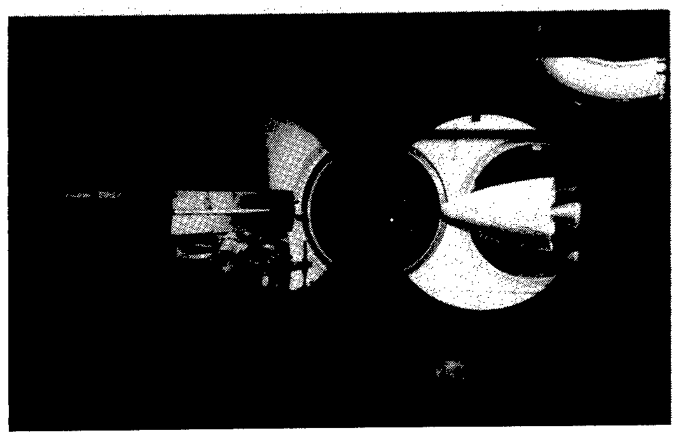
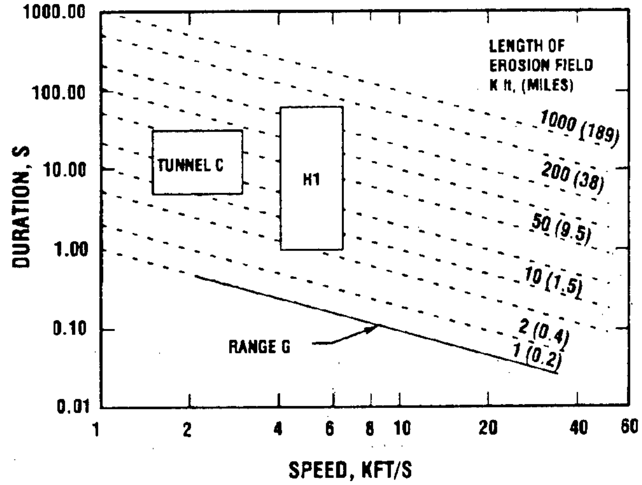


Fig. 8. Radome exposed to an ice field in tunnel C.

The weather/erosion test methodology is similar to that of aerothermal in that ground testing starts at the material level and progresses to the component and structural level. Two common test techniques for evaluating and comparing material, component, and structural response are the exposure of the test article to a single impact or multiple impacts. The development of a weather/erosion test capability at AEDC has focused on the multiple impact techniques which have been developed for all three facilities. A series of diagnostics techniques[12] such as a double-pulsed holography system, laser doppler velocimeter, and other laser screen systems have been developed to characterize the particle fields. Figure 9 summarizes the AEDC weather/erosion facilities and capabilities.

FACILITIES	TYPE	ENVIRON-MENT	PARTICLE VELOCITY, KFT/S	MAX EXPOSURE TIME
RANGE G	TRACK/FREE-FLIGHT RANGE	RAIN, ICE, SNOW, DUST	2.5 TO 20	< 1 SEC
H1	ARC HEATER	DUST	4 TO 7	SEC→MIN
TUNNEL C	CONTINUOUS	ICE	1.5 TO 3	SEC→HRS



- WIDE RANGE CONDITIONS
  - (SUPERSONIC → HYPERSONIC)
  - SYNERGISTIC AEROTHERMAL WEATHER/EROSION

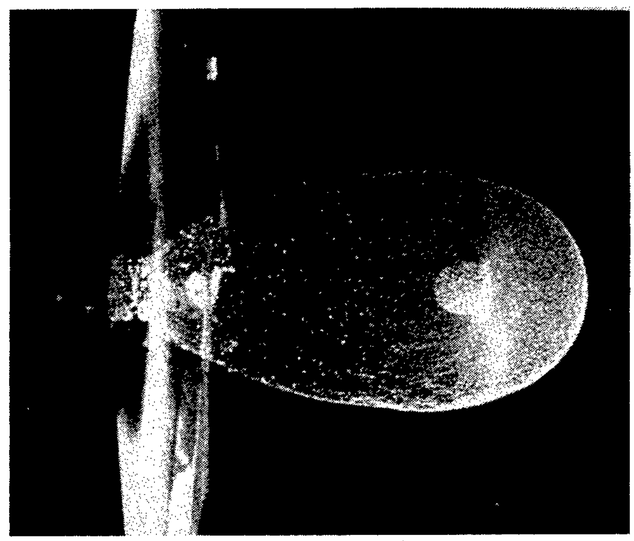
Fig. 9. Supersonic/hypersonic weather/erosion facilities/capabilities.

Impact/Lethality

AEDC has a long history of conducting hypervelocity impact research and testing in Ranges G and S1. Both ranges use two-stage, light-gas launchers to propel projectiles to velocities up to 8 km/sec. To support a wide range of test objectives, diagnostic systems have been developed for application in both ranges. These diagnostic systems include photography (X-rays (hard and soft), lasers, and high-speed framing cameras), impact signatures (spectrometers and radiometers), and target instrumentation (pressure, shock, and strain gages).

The general objectives of impact/lethality tests are to characterize effects of hypervelocity impacts on materials, components, and structures. Current test programs fall into two classes, assessment of the lethality of kinetic energy weapons and assessment of space debris impacting space systems. For lethality assessment, scaled projectiles and full and subscale targets (including flight hardware) are used. Projectiles which have been successfully launched include standard models such as spheres, long rods, and slugs as well as complex models such as fragmented projectiles, fluid models, and segmented rods. For assessment of space-debris impact effects, targets range from flat plates to full-scale hardware such as satellites. One of the key objectives of both lethality and space-debris testing is assessment of make-up and propagation rate of the debris cloud which results from high-speed impacts. Measurement techniques[13] developed include soft-catch of debris fragments and use of witness plates to examine damage caused by debris particles. Figure 10 is a summary of the impact/lethality test capabilities at AEDC.

LASER PHOTOGRAPH OF DEBRIS CLOUD



LETHALITY/IMPACT CAPABILITIES
- VELOCITY TO 8 KM/S
- LARGE LAUNCH PACKAGES 0.5-IN. TO 3.3-IN.
- HIGH PRODUCTIVITY-ALTITUDE SIMULATION (SEA LEVEL → SPACE)
- EXTENSIIVE DIAGNOSITCS
  - PHOTOGRAPHY
  - IMPACT SIGNATURE
  - SOFT CATCH
  - WITNESS PLATES
  - TARGET INSTRUMENTATION

Fig. 10. Hypervelocity impact/lethality capabilities in Ranges G and S1.

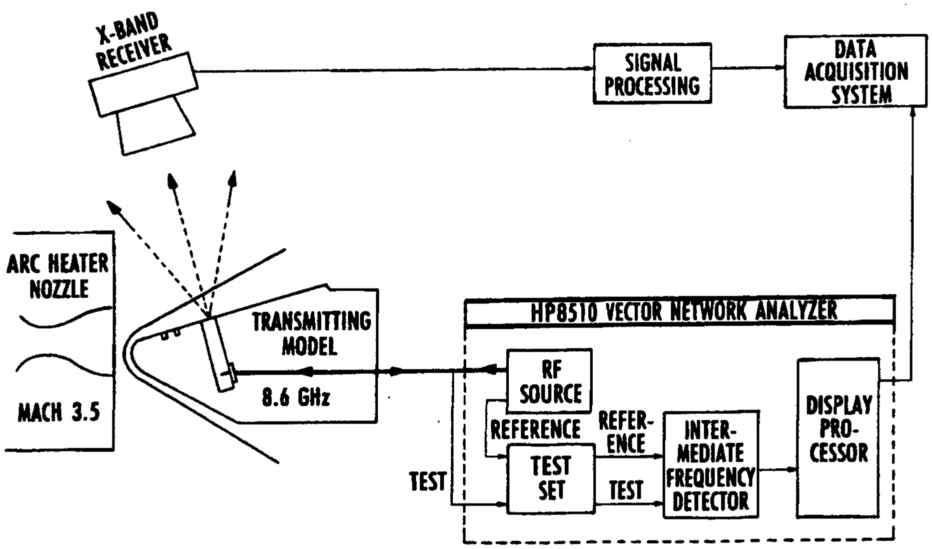


Fig. 11. Hot RF antenna window test technique.

Test Support and Technology

AEDC is unique because of the comprehensive infrastructure which has been developed to meet a wide range of T&E needs. Available services include model design and fabrication, instrumentation selection and installation, data reduction programming, photographic and flow visualization coverage, data certification, and reporting. General services available at AEDC include engineering design, machine and fabrication shops, a central computer complex, and calibration, metallurgical, and photographic laboratories. In addition, AEDC has a significant investment in developing technologies focusing on the development and improvement of facilities, test techniques, and instrumentation. As a national leader in aerospace ground test and evaluation, AEDC has recently aggressively promoted applying the center's expertise and test support capabilities outside of the AEDC complex.

RF Interaction Test Techniques

A recent test technique[14] (illustrated in Fig. 11) has been developed for evaluating radio frequency (RF) performance of hot antenna windows exposed to aeroheating environments in high-pressure arc-heated flows. Transmitted power and phase and reflection coefficient of selected antenna window materials are measured during and after exposure to the severe heating environment to provide data quantifying antenna degradation due to thermal effects and ablation. Window surface recession rate, surface temperature, and in-depth window temperature are measured to provide the basis for correlating window performance with complex permittivity changes due to temperature and with detuning of the filled waveguides due to ablation and surface roughening. Previous tests have been completed at X-band (9 GHz) and a current effort is ongoing to provide similar data for GPS antennas.

In the Range G facility, a test technique has been developed to evaluate the transmission and absorption of RF signals through a plasma sheath generated during portions of the hypersonic flight regime. The objective of the plasma effects technique is to obtain attenuation and phase shift data caused by the plasma/RF interaction to validate computer codes used in predicting the beam pointing error (bore sight error). The onboard approach (shown in Fig. 12) uses an active RF transmitter on a free-flight model to transmit a signal through a plasma sheath generated during flight. Transmitters and receiving instrumentation have been developed for 34.5 GHz and 94 GHz.

Analysis and Computational Capabilities

A broad range of analysis and computational capabilities are available which include Computational Fluid Dynamics (CFD), aerodynamic math models, hypersonic wake signatures, ablation/recession, thermal and structures analysis, and impact analysis.

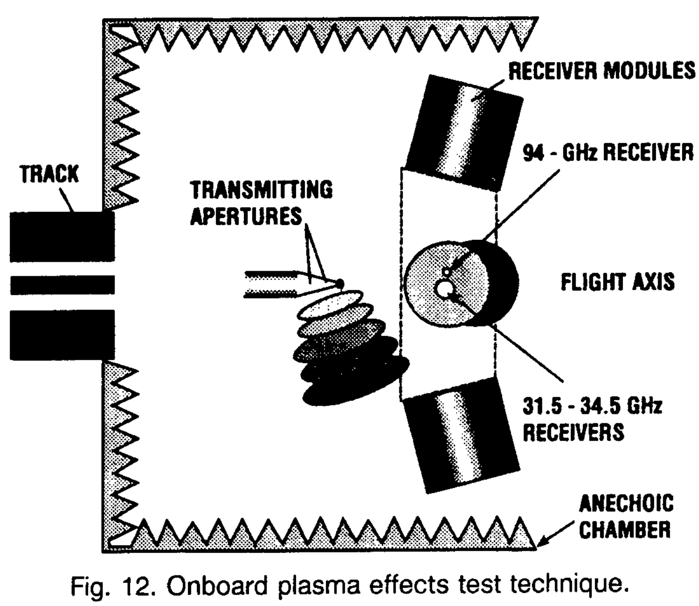


Fig. 12. Onboard plasma effects test technique.

CFD is used routinely in flow regimes ranging from subsonic through hypersonic with all appropriate flow physics included in the analyses. A large collection of computer codes is operational, including time-dependent and space-matching Navier-Stokes solvers (viscous) and very efficient Euler (inviscous) solvers and boundary layer codes. In the hypersonic regime, CFD tools are available to determine gas jet effects, control surface effectiveness, and ablated nose effects as well as overall vehicle aerodynamics and heating. Aerodynamic math models can be developed to calculate aerodynamic coefficients using a database. Hypersonic wake analysis capabilities have been developed to predict and interpret the optical and radar signatures. Codes such as the ABRES Shape Change Code (ASCC-86) are available for prediction of axisymmetric shape change phenomenology and material response to the aeroheating environment. AEDC has a wide range of thermal analysis and structural analysis methods. Examples of types of thermal analysis which are routinely performed are aerodynamic heating, radiant heat exchange, internal heat conduction, and cooling systems. Examples of types of structural analysis which can be performed are stress analysis, thermal stress analysis, vibrational dynamic analysis, and fracture mechanics. The impact analysis capability makes use of hydrocodes to provide prediction of the hypervelocity-impact events.

Arc Heater Technology

A technology program is currently underway to develop the next generation of high-pressure, high-enthalpy segmented arc heaters. The program includes the development of new contoured high-pressure nozzles and stilling/mixing chamber technology. The program also supports research into the development of a new class of high-powered arc heaters for high-enthalpy, high-pressure, high-mass-flow aerothermal and propulsion test applications. The arc-heater technology program at AEDC features: (1) design and development of operational concepts based upon experimental testing to improve the reliability and performance of segmented arc heaters, (2) design, development, and evaluation of a 3-in.-bore segmented arc heater (H3) with an operational performance up to (and hopefully beyond) 200 atm, (3) development and validation of analytical models of the primary physics and fluid mechanics of arc-heaters, (4) development of a validated design procedure for effective nozzle and throat cooling, and (5) development of a control mixer to improve flow uniformity. The aerothermal flight simulation envelope for the H3 arc heated test unit is shown in Fig. 13.

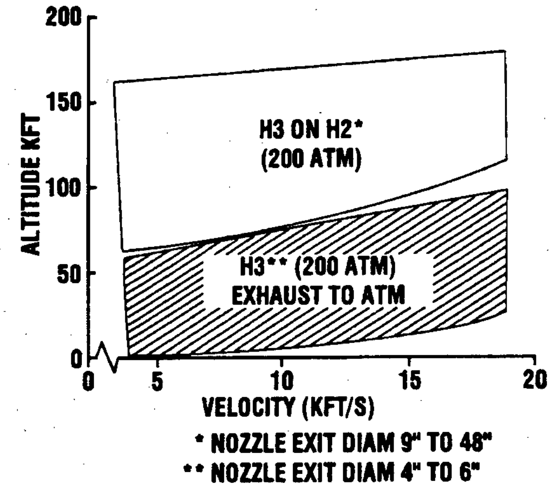


Fig. 13. H3 arc heated test unit aerothermal capabilities.

Hypersonic Real Gas Facility Development

A technology program is currently underway to develop the free-piston shock tunnel discussed previously. The major efforts undertaken as part of this program are: (1) development of a high-pressure diaphragm and seal, (2) development and demonstration of flow diagnostics, and (3) shakedown/calibration test program. The approach for characterizing and expanding the facility envelope will be to start an initial series of facility shots at low pressure (total pressure approaching 20,000 psia). Measurements of the free-stream flow properties will be obtained using a pitot rake and the nonintrusive Planar Laser-Induced Fluorescence (PLIF) and Coherent Anti-Stokes Raman Scattering (CARS) diagnostics. These initial shots will be used to validate and refine the facility performance model and to provide initial comparisons with CFD predictions. The next step will be to take the facility to higher pressures (with a goal of stagnation pressure up to 10,000 atm).

Enhanced Impact Development

A program is underway to develop two new hypervelocity-impact test techniques: three-stage gun and counterfire. The objective of this development is to provide impact velocities in the 8 to 14 km/sec range, which is well beyond what is available using conventional, two-stage launcher technology. The hypervelocity-impact technology program includes, in addition to launcher development, improvement of computer-based impact-modeling capabilities and techniques and further development of measurement techniques to provide impact-debris mass and velocity distribution data.

Summary

Ground testing of materials/structures, components, and flight hardware is of critical importance in the development of systems and technology for high-speed missile interceptors. While some deficiencies in hypersonics ground test capability exist both nationally and worldwide, extensive ground test capability currently exists at Arnold Engineering Development Center. An overview of the ground test facilities and methodologies presently existing at AEDC has been provided. Proven test techniques for aerodynamic, aerothermal, weather/erosion, and impact/lethality testing have been summarized. Finally, an overview of test support capabilities, including diagnostics and instrumentation, analysis support, and various ongoing technology programs, has been given.

References

1. Cantrell, M., VanHorn, T., and Muras, A.D. "Endoatmospheric LEAP." AIAA-92-1215, February 1992.

2. *Test Facility Handbook* (Eleventh Edition). Arnold Engineering Development Center (AEDC), Arnold AFB, TN, June 1979.

3. Cable, A. J. "Upgrade of Ballistic Range Facilities at AEDC: The Half-Way Point." AIAA 92-3997, July 1992.

4. VKI/AEDC Special Course. "Methodology of Hypersonic Testing," von Karman Institute for Fluid Dynamics, Rhode Saint Genese, Belgium, February 1993.

5. Matthews, R. and Crosswy, F. "Testing Capabilities at AEDC for Development of Hypersonic Vehicles." AIAA-91-5027, December 1991.

6. Stetson, K. F. and Kimmel, R. L. "On Hypersonic Boundary-Layer Stability." AIAA-92-0737, January 1992.

7. Matthews, R. K., Nutt, K. W., Wannenwetsch, G .D., and Kidd, C. T. "Development in Aerothermal Test Techniques at the AEDC Supersonic-Hypersonic Wind Tunnels." AIAA-84-1803, June 1984.

8. Williams, W. D., Price, L. L., and Stepanek, S.A. "Application of Electron Beam Fluorescence for Characterization of Hypersonic Facility Flows." AIAA-92-3898, July 1992.

9. Matthews, R. K., Stepanek, S. A., and Stallings, D. W. "Aerothermal Test Methodology for the Development for Structural Components for Hypersonic Vehicles." AIAA-91-1441, June 1991.

10. Sherrouse, P. and Carver, D. "Demonstrated Real-Time Recession Measurements of Flat Materials During Testing in High-Enthalpy Flows." AIAA-92-0765, January 1992.

11. Norfleet, G. D., Hendrix, R. E., and Raper, R. M. "Development of an Aeroballistic Range Capability for Testing Re-Entry Materials." AIAA-74-609, July 1974.

12. Beitel, G. R. and Matthews, R. K. "A New Rain/Ice Test Capability to Simulate Flight." AIAA-86-9824, April 1986.

13. Wilbeck, J. S. and Young, R. P, Jr. "Experience with Techniques for Characterizing Debris Generated During Hypervelocity Impact Testing." AIAA-92-1586, March 1992.

14. Smith, D. M. et al. "An Experimental Technique for Measuring RF Performance of Hot Antenna Windows in the AEDC HEAT-H1 Arc-Heated Test Unit." Presented at the Twentieth Symposium on Electromagnetic Window at Georgia Institute of Technology, Atlanta, GA, September 1992.